A Possible Link between the Weddell Polynya and the Southern Annular Mode*

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ABSTRACT

Shortly after the advent of the first imaging passive microwave sensor on board a research satellite an anomalous climate feature was observed within the Weddell Sea. During the years 1974–1976, a 250×10^3 km^2 area within the seasonal sea ice cover was virtually free of winter sea ice. This feature, the Weddell Polynya, was created as sea ice formation was inhibited by ocean convection that injected relatively warm deep water into the surface layer. Though smaller, less persistent polynyas associated with topographically induced upwelling at Maud Rise frequently form in the area, there has not been a reoccurrence of the Weddell Polynya since 1976. Archived observations of the surface layer salinity within the Weddell gyre suggest that the Weddell Polynya may have been induced by a prolonged period of negative Southern Annular Mode (SAM). During negative SAM the Weddell Sea experiences colder and drier atmospheric conditions, making for a saltier surface layer with reduced pycnocline stability. This condition enables Maud Rise upwelling to trigger sustained deep-reaching convection associated with the polynya. Since the late 1970s SAM has been close to neutral or in a positive state, resulting in warmer, wetter conditions over the Weddell Sea, forestalling repeat of the Weddell Polynya. A contributing factor to the Weddell Polynya initiation may have been a La Niña condition, which is associated with increased winter sea ice formation in the polynya area. If the surface layer is made sufficiently salty due to a prolonged negative SAM period, perhaps aided by La Niña, then Maud Rise upwelling meets with positive feedback, triggering convection, and a winter persistent Weddell Polynya.

1. Introduction

With the advent of scanning passive microwave sensors on board polar orbiting satellites in late 1972, the polar community entered the era of viewing sea ice conditions poleward of the outer ice edge with near-synoptic clarity. The waxing and waning of the seasonal sea ice cover in the Southern Ocean, whose northern ice edge was previously observed only sporadically from ship, was now exposed in its entirety. The satellite sensors in their second year of operation revealed a large ice-free region during the winter near the Greenwich meridian and 65°S, which is referred to as the Weddell Polynya (Zwally and Gloersen 1977; Carsey 1980; Gordon and Comiso 1988; Fig. 1). The Weddell Polynya, averaging 250×10^3 km^2 in size, was present during the entire austral winters of 1974, 1975, and 1976.

The Weddell Polynya formed just south of the central axis of the cyclonic (clockwise) flowing Weddell gyre. The Weddell gyre, which dominates the circulation of the Weddell Sea, stretches from the Antarctic Peninsula to roughly 20° or 30°E and from the southern limits of the Antarctic Circumpolar Current near 58°S to the margins of Antarctica [Klatt et al. (2005) provide the most recent overview of the Weddell gyre]. The stratification within the Weddell gyre is characterized by a thick layer of relatively warm, saline deep water drawn from the lower Circumpolar Deep Water. Along the southern limb of the gyre the warm deep water is >1.0°C, with salinity >34.7. The warm deep water is capped by the ~100-m-thick surface layer of near-freezing temperature in the winter. In the summer a warmed surface layer induces a temperature minimum near 50–100 m marking a residue of the winter condition. The surface layer is separated from the warmer deep water by a weak pycnocline (density gradient). Below the warm deep water are the Weddell Sea Deep Water and Weddell Sea Bottom Water, both cooled and freshened relative to the warm deep water by input from the continental margins of Antarctica.

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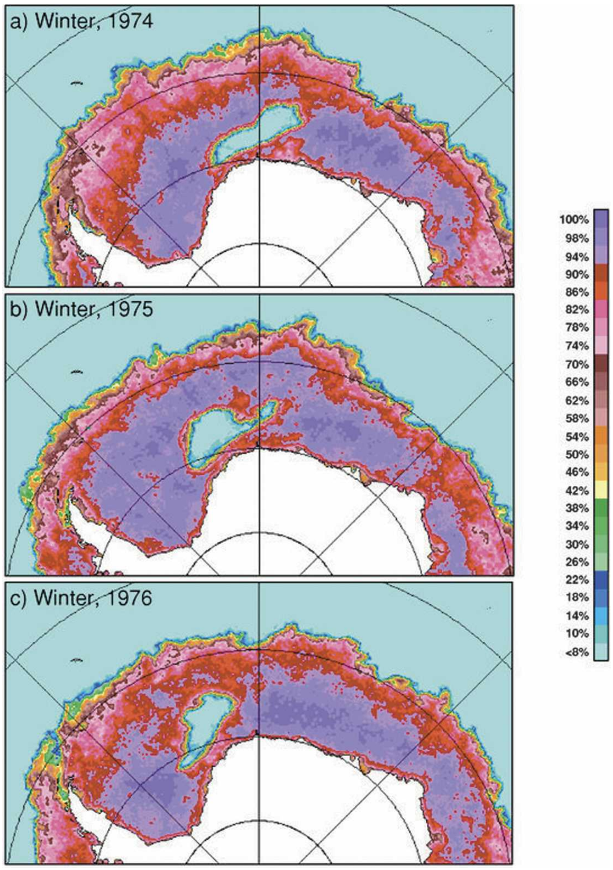

FIG. 1. Color-coded sea ice concentration maps derived from passive microwave satellite data in the Weddell Sea region during (a) 30 Aug 1974, (b) 30 Aug 1975, and (c) 29 Aug 1976. The Weddell Polynya is the extensive area of open water (in blue) near the Greenwich meridian roughly between 65° and 70°S. (Adapted from Gordon and Comiso 1988.)

During each winter, the polynya area shifted westward at a rate of 0.013 m s^{-1}, the approximate barotropic flow within the Weddell gyre once away from the topographic effects of the continental margins and Maud Rise (Gordon 1978, 1982). As the Weddell Polynya was observed near the very start of the satellite-based time series one might have reasonably expected that a winter persistent polynya was the norm, but since 1976 a winter-long polynya has not been observed. What has been observed are much smaller (10×10^3 km^2), sporadic polynyas with characteristic time scale of 1 week in the vicinity of Maud Rise near 65°S, 2°E (Comiso and Gordon 1987; Lindsay et al. 2004) induced by circulation-topographic interaction (Gordon and Huber 1990).

The Weddell Polynya of the mid-1970s represents an anomaly relative to the last three decades of direct sea ice observations. Comparison of water column characteristics before and after the Weddell Polynya indicates that it was maintained in the cold winter months by ocean convection reaching to a nearly 3000-m depth that injected relatively warm deep water into the surface water (Gordon 1978, 1982; Fig. 2). The Weddell Polynya is an example of a sensible heat polynya (the ocean to atmosphere heat flux is maintained by lowering the surface water temperature) in contrast to latent heat polynyas (where ocean to atmosphere heat flux is maintained by latent heat release of forming sea ice, which is subsequently removed by the wind) that form along much of the coastline of Antarctica. An estimate of the 3-yr average winter ocean heat lost to the atmosphere within the Weddell Polynya is 136 W m^{-2} (Gordon 1982). This ocean heat loss is supported by deep reaching ocean convection of 1.6 to 3.2 Sv (1 Sv $\equiv 10^6$ m^3 s^{-1}) that exchange freezing-point surface water with relatively warm Weddell Deep Water. Moore et al. (2002) using National Centers for Environmental Prediction–National Center for Atmospheric Research (NCEP–NCAR) data find that buoyancy loss within the Weddell Polynya is larger than determined by Gordon (1982) so that the ocean convection may have been significantly more vigorous. However, the NCEP freshwater flux estimate does not include the convergence of freshwater into the polynya associated with the movement of sea ice floes (e.g., by wind stress associated with passing weather systems) with subsequent melting. Gordon (1982) and Comiso and Gordon (1987) suggest that the influx of sea ice from the polynya edges acts to dilute the deep-water salt injected into the surface layer and therefore is a factor in modulating the convective intensity.

The sea surface salinity measured in the austral summer of 1977 shows that in the area of the Weddell Polynya the surface water was markedly saltier than that of the surrounding area and relative to the regional climate average (Fig. 3). It is reasonable to conclude that the salty surface layer is a consequence of the upward mixing deep-water salt during the winter months coupled with the lack of summer sea ice melt. Salty surface water preconditioned the region for a repeat of the polynya the following year. It is hypothesized (Gordon 1978, 1982) that the slow drift westward of the convective region with the overall circulation of the Weddell gyre by the winter of 1977 carried it into the high shear (dv/dx) of the western boundary current of the Weddell gyre, where reduced east–west dimensions enabled surrounding sea ice drift by synoptic weather systems to flood the area with meltwater thus shutting down the potential for deep reaching convection (Comiso and Gordon 1987).

There has been significant rebound in deep-water temperature since the Weddell Polynya. Smedsrud (2005) finds that the area affected by the Weddell Polynya warmed by $\sim 14 \times 10^9$ J m^{-2} from 1977 to 2001. The warming rate within the southern westward flowing limb is about the warming rate observed within the Antarctic Circumpolar Current of 0.034°C $decade^{-1}$ (Gille 2002), indicating that the Weddell Sea Deep Water warming is an advective effect. At the Greenwich meridian the Weddell Deep Water was warmest at the end of the 1990s, decreasing slightly since 1998 (Fahrbach et al. 2004), particularly in the vicinity of Maud Rise (Smedsrud 2005).

Using observational data we present the hypothesis that the Weddell Polynya was primarily the consequence of a prolonged negative phase of the Southern Annular Mode (SAM), with a possible contributing role of the La Niña phase that preceded the polynya.